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Dear Sir or Madam:

Please find enclosed a copy of the Annual Report for the NASA Grant Number NAGW-4452. The grant was awarded to Dr. John Bahcall to provide research support for Dr. Sofia Kirhakos to work on "Studies of Quasar Absorption Lines and the Host Galaxies of Bright Quasars". Two copies of the papers published during the last grant year are also included.

Sincerely yours,

Sofia Kirhakos

Sofia Kirhakos

Annual Report

NASA Grant Number NAGW-4452 was awarded to Dr. John Bahcall to provide research support for Dr. Sofia Kirhakos to work on "Studies of Quasar Absorption Lines and the Host Galaxies of Bright Quasars". In this report we describe the progress made over the last grant year.

1. Results Obtained with the Grant to Date

1.1 Quasar Absorption Lines

The main goal of this program is to produce a homogeneous data base, using ground-based and Hubble Space Telescope (*HST*) observations of quasars with redshifts over the entire range $0.15 \leq z \leq 4.0$, to study the properties of the intergalactic medium and of the gaseous content of galaxies, and in particular to look at the evolution of gaseous systems over a significant period of cosmic time.

The *HST* Quasar Absorption Line Key Project has obtained high signal-to-noise ratio ultraviolet spectra of 90 quasars using the *HST* Faint Object Spectrograph (FOS). We have developed an absorption-line reduction software, and in the period covered by the grant, have finished calibrating all the data ($\sim$ 200 spectra), including spectra obtained in Cycle 4. We have already generated continuum fits for the majority of the spectra. The principal use of the continua is to normalize the data for the identification of relatively weak, narrow absorption lines. The absorption lines are selected, measured and identified objectively. The criteria for line identifications take account of atomic-physics constraints, the observed characteristics of the absorption spectra, the presence or absence of other expected absorption lines, the number of candidate absorption lines corresponding to a particular redshift, the strengths of candidate absorption lines relative to the strengths of Lyα, and, in some cases, the relative strengths of metal lines from different ions.

We report in Bahcall *et al.* (1996, ApJ, 457, 19) the analysis of the spectra for four quasars with redshifts between 1.0 and 1.3. We show that clumps of Lyα lines are physically associated with about half of the extensive metal-line systems found, demonstrate that all four Lyman-limit systems found correspond to extensive metal-line absorption systems, and present a physically associated pair of extensive metal-line absorption systems at $z = 0.95$. We also determine the evolution of Lyα absorption lines at redshifts less than 1.3 by combining results for 13 smaller redshift quasars analysed previously (Bahcall *et al.* 1993, ApJS, 87,1)

1.2 *HST* Images of Low-Redshift Quasars

We have made much progress in our program to image low-redshift quasar host galaxies in the first year of the awarded grant. We have completed observations of 20 intrinsically luminous quasars with redshifts between 0.16 and 0.29, using the Wide-Field Camera 2 (WFC2) of the *HST*. The observations were obtained through the F606W filter, which is similar to the V band, but slightly redder. This filter was chosen because of its high throughput, and we chose WFC2 over the Planetary Camera because the scattered light in the former is about five times less.

All quasars were located at a distance of $4.3'' \pm 1.2''$ from the center of the WFC2 CCD 3, and were observed for three separate exposures of approximately 1400 s, 500 s, and 200 s. The innermost regions of the quasar images are saturated in all of the exposures out to a radius $\approx 0.3''$. In some cases the host galaxy is clearly seen in the images without PSF subtraction, indeed they are even seen in our shortest (200 sec) exposures (for example, PG 0052+251, PHL 909, 0316-346, PG 1012+008, HE 1029-140, PG 1309+355, PG 1402+261, and PKS 2349-014).

We fit a stellar point-spread function (PSF) to each quasar and subtracted it to search for underlying diffuse light from hosts. The stellar PSF was determined using a set of images of an isolated $V = 10.5$ mag star (F141) in M67, covering the saturation range present in the quasar images. The best fit was determined minimizing the differences between the quasar and the PSF using a χ^2-routine calculated using two distinct approaches: azimuthal averages and narrow regions centered on the difraction spikes. The two methods gave similar results. We have published four papers describing the results of the imaging program in the period covered by the grant, and have submitted a fifth one. We have learned that quasars occur in an extraordinary variety of diffuse environments, that range from apparently normal spiral and elliptical host galaxies, to complex systems of gravitationally interacting components, to low surface brightness host galaxies.

In Bahcall, Kirhakos and Schneider (1995a, ApJ, 450,486) we report on the first eight quasars observed, and details of the analysis procedure and the extensive tests performed. Three candidate host galaxies were detected and seven companion galaxies brighter than $M_V = -16.5$ were found within 25 h^{-1}kpc ($\Omega_0 = 1.0$) of the quasars; three of the companions are located closer than $3''$ (6 h^{-1}kpc projected) from the quasars.

HST images of PKS 2349-014 (Bahcall, Kirhakos and Schneider, 1995b, ApJ, 447, L1). show a spectacular case of what seems to be a quasar triggered by gravitational interaction. Two thin wisps almost completely surround the quasar and a faint off-center extended nebulosity is detected over a region of 35 h^{-1}kpc $\times$ 50 h^{-1}kpc. A small companion galaxy is located at a projected distance of $1.8''$ from the center of the quasar light; if located at the distance of PKS 2349-014, it has an intrinsic size and luminosity similar to the Large Magellanic Cloud.

In Bahcall *et al.* 1995 (ApJ, 452, L91) we present a direct comparison between the visual image of the jet of the quasar 3C273 obtained with the *HST*-WFPC2 and a new radio map made with the MERLIN array at 18 cm. The two maps are aligned to an accuracy of $0.020''$; this accuracy is achieved because both the quasar and the jet are contained in both the radio and optical images. The start of the optical jet is marked by an elongated knot which appears identical at radio and optical wavelengths. Other knots in the optical jet correspond to narrow oblique features within the radio outline. The knots may trace the current location of a narrow, perhaps helical jet lying within the outlines of the older radio cocoon.

In Bahcall, Kirhakos and Schneider (1995c, ApJ, 457,557) we report observations of PHL 909 and PG 0052+251. *HST* images show that these luminous radio-quiet quasars each occur in an apparently normal host galaxy. The host of PHL 909 is an elliptical galaxy ($\sim$ E4) and the host of PG 0052+251 is a beautiful spiral ($\sim$ Sb). We have performed aperture photometry (between $0.5''$ and $10.0''$) on the PSF-subtracted images and found $M_V = -20.9$ mag for the elliptical host of PHL 909, and $M_V = -21.1$ mag for the host of PG 0052+251. We also measured the relative positions and brightness of the eleven brightest HII regions we found in PG 0052+251. As an example of the impact of our work, Joseph Miller recently successfully obtained spectra of some of these HII regions using the Keck Telescope (private communication): they have the same redshift as the quasar.

A study of clustering of galaxies around the 20 quasars is described in Fisher *et al.* 1996 (submitted). We find a significant enhancement of galaxies within a projected separation of $\gtrsim 100\ h^{-1}$kpc of the quasars. The galaxy distribution around the quasars is consistent with the observed slope of the galaxy/galaxy correlation function, but has an amplitude 3.8 ± 0.8 times higher. Our results reinforce the idea that low redshift quasars are located preferentially in groups of $10 - 20$ galaxies rather than in rich clusters. We see no significant difference in the clustering amplitudes derived from radio-loud and radio-quiet subsamples.

2. List of Publications

Bahcall, J.N., Bergeron, J., Boksenberg, A., Hartig, G.F., Jannuzi, B.T., Kirhakos, S., Sargent, W.L.W., Savage, B.D., Schneider, D.P., Turnshek, D.A., Weymann, R.J., and Wolfe, A.M., 1996, ApJ, 457, 19.

Bahcall, J.N., Kirhakos, S., and Schneider, D.P., 1995a, ApJ,450,486.

Bahcall, J.N., Kirhakos, S., and Schneider, D.P., 1995b, ApJ,447,L1.

Bahcall, J.N., Kirhakos, S., and Schneider, D.P., 1995c, ApJ,457,557.

Bahcall, J.N., Kirhakos, S., Schneider, D.P., Davis, R.J., Muxlow, T.W.B., Garrington, S.T., and Conway, R.G., 1995, ApJ,452,L91.

Fisher, K. B., Bahcall, J.N., Kirhakos, S., and Schneider, D.P., 1996, submitted (ApJ)

Stengler-Larrea, E.A., Boksenberg, A., Steidel, C.C., Sargent, W.L.W., Bahcall, J.N., Bergeron, J., Hartig, G.F., Jannuzi, B.T., Kirhakos, S., Savage, B.D., Schneider, D.P., Turnshek, D.A., and Weymann, R.J., 1995, ApJ, 444, 64.